

Class-E Silicon Carbide VHF Power Amplifier For Space Applications

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Outline

- High efficiency, class-E VHF power amplifiers
- Active device requirements and available technologies
- Restrictions imposed by space applications
- Amplifier design with silicon carbide (SiC) MESFET
- Simulated and experimental results

Motivation

- Switch-mode operation (i.e. class-E) involves high peak drain/collector voltage
- GaAs transistors are inherently low voltage devices
- LDMOS devices are not suitable for flight (oxide layer susceptible to total radiation dose)
- Silicon carbide (SiC) and gallium nitride (GaN) are ideal for high efficiency space applications

Class-E amplifiers

- Very high dc to RF efficiency by operating the active device as a switch
- High peak drain or collector voltage (almost 4x class AB)
- High breakdown voltage devices are ideal candidates
- Linearity can be restored by amplitude modulation of the drain voltage (HELAPS)

Flight hardware issues

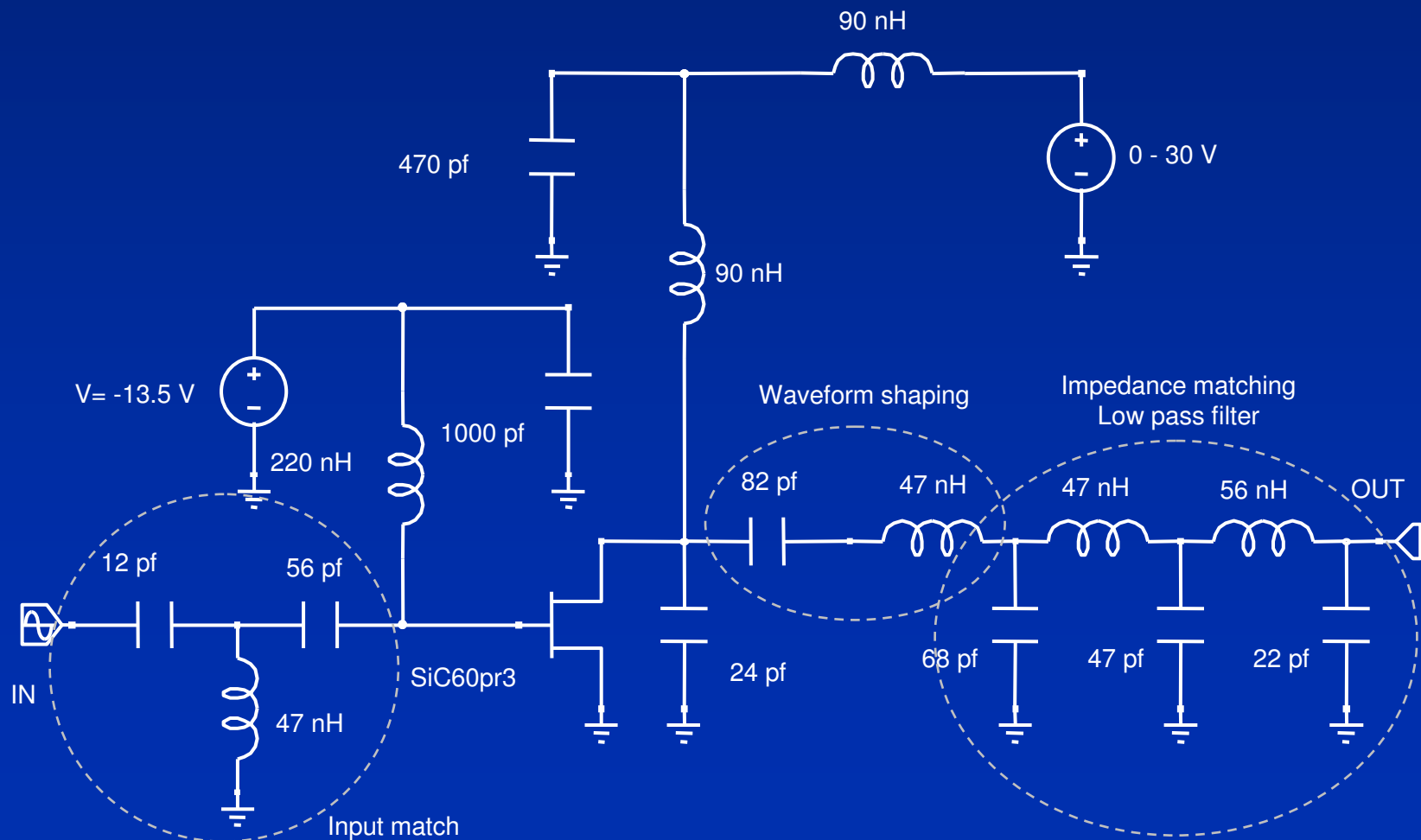
- Radiation hardness becomes a concern
- GaAs is the dominant semiconductor in space applications
- GaAs devices have a low breakdown voltage – hard to operate in class-E
- LDMOS transistors have higher breakdown voltage, but generally cannot be used in high radiation environments (oxide layer)

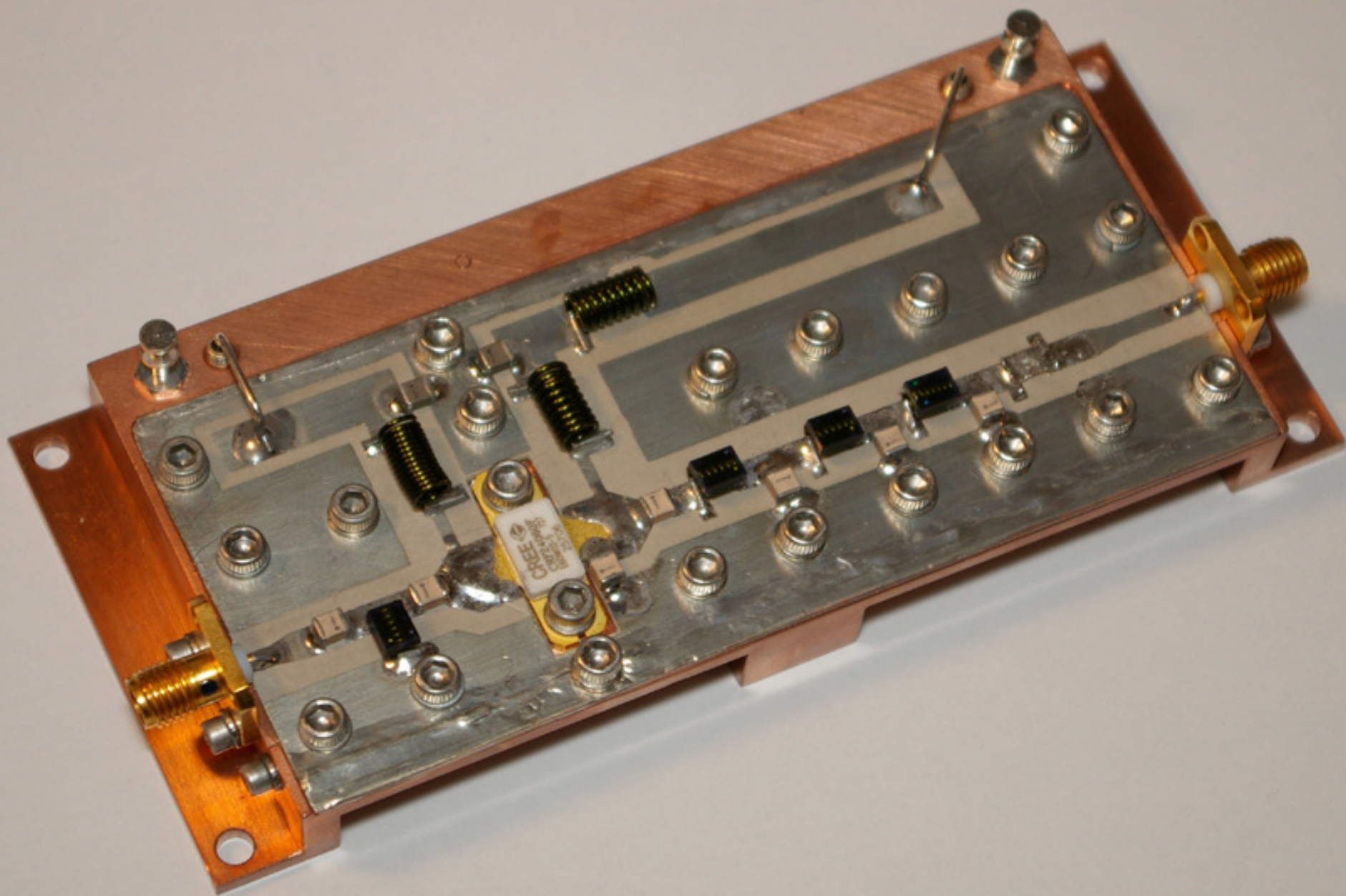
SiC and GaN in space?

- No oxide layer
- SiC solar cells have been flown
- SiC has excellent temperature properties
- Both SiC and GaN are ideal for class-E operation
- Weatherford and Anderson, “Historical perspective on radiation effects in III-V devices,” *IEEE Transactions on Nuclear Science*

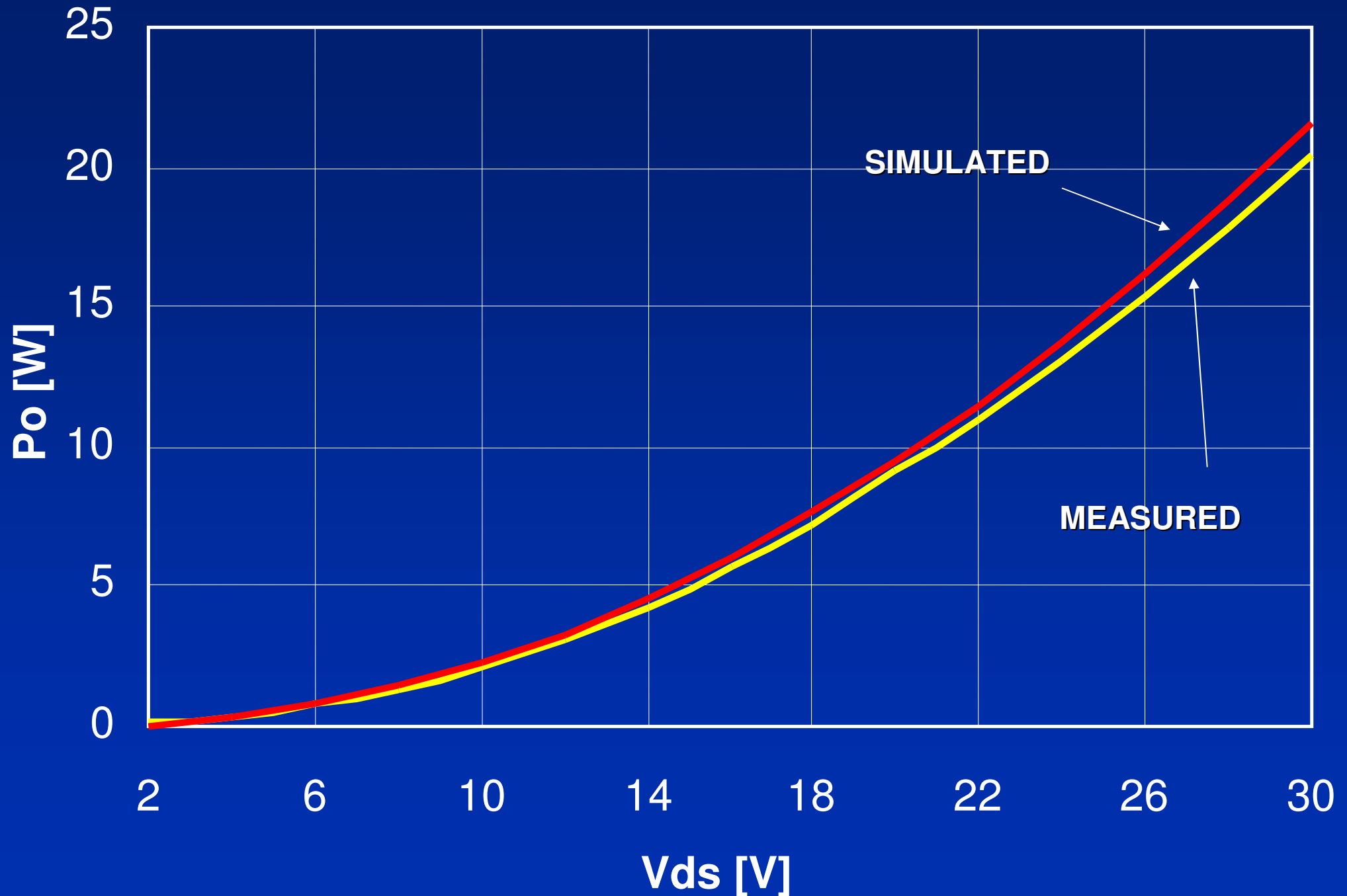
SiC Class-E amplifier design

- Classic class-E schematic (Sokal)
- SiC MESFET SiC60pr by Cree
- $Q=2.27$, $V_{ds}=30V$, $R_L=18\text{ ohms}$
- Output low pass filter
- Decoupling allows drain modulation
- No tuning elements

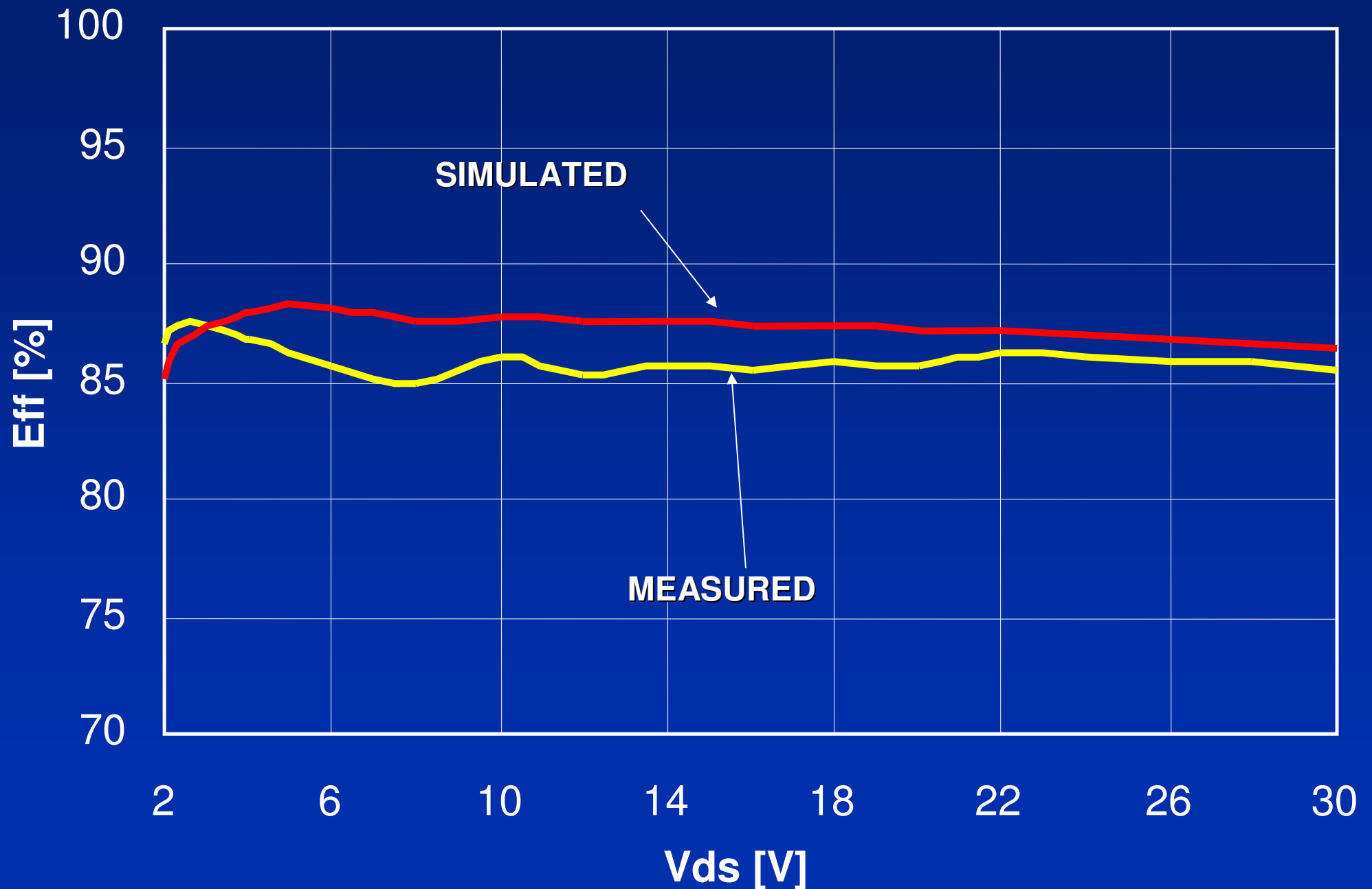




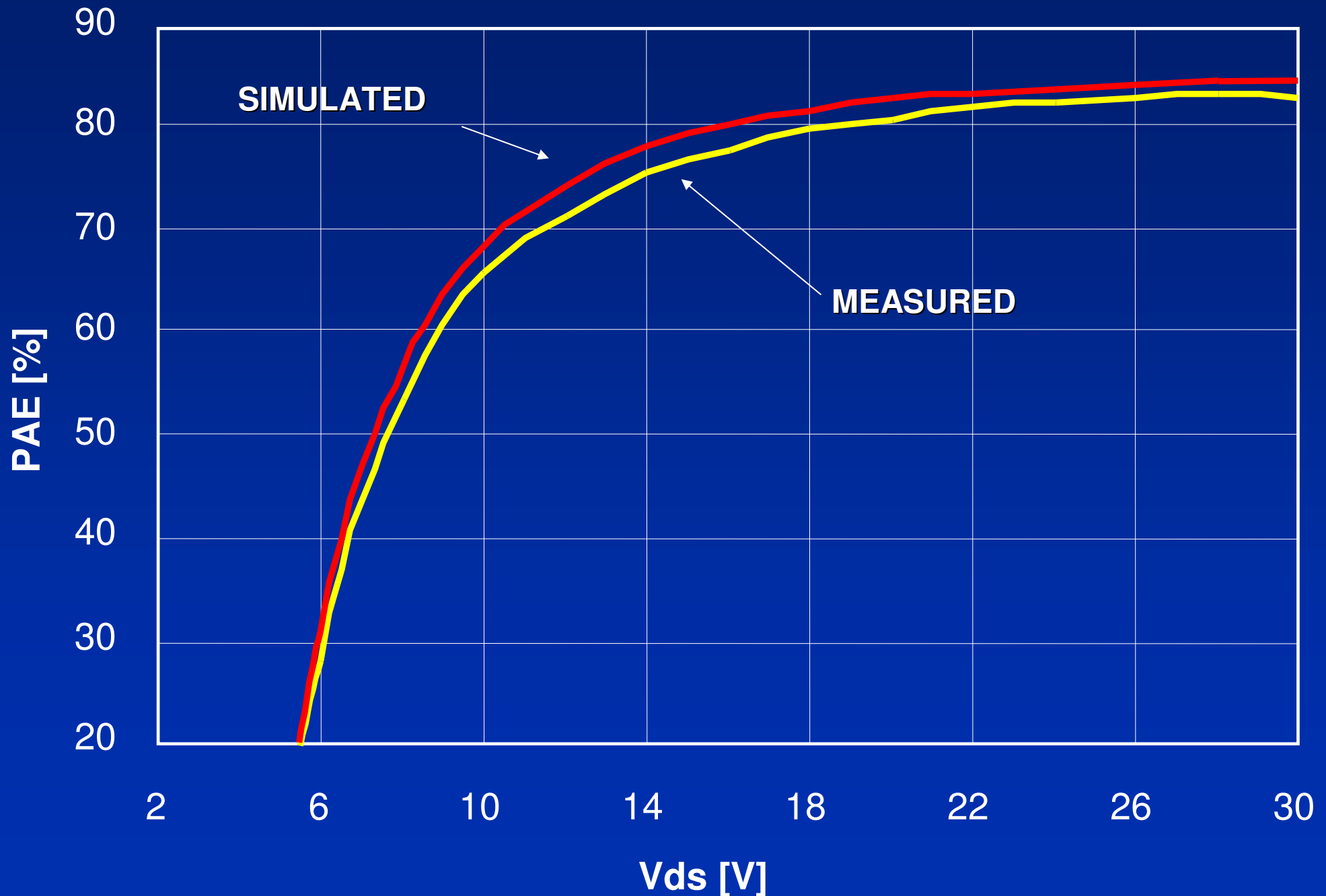
Output power vs. drain voltage



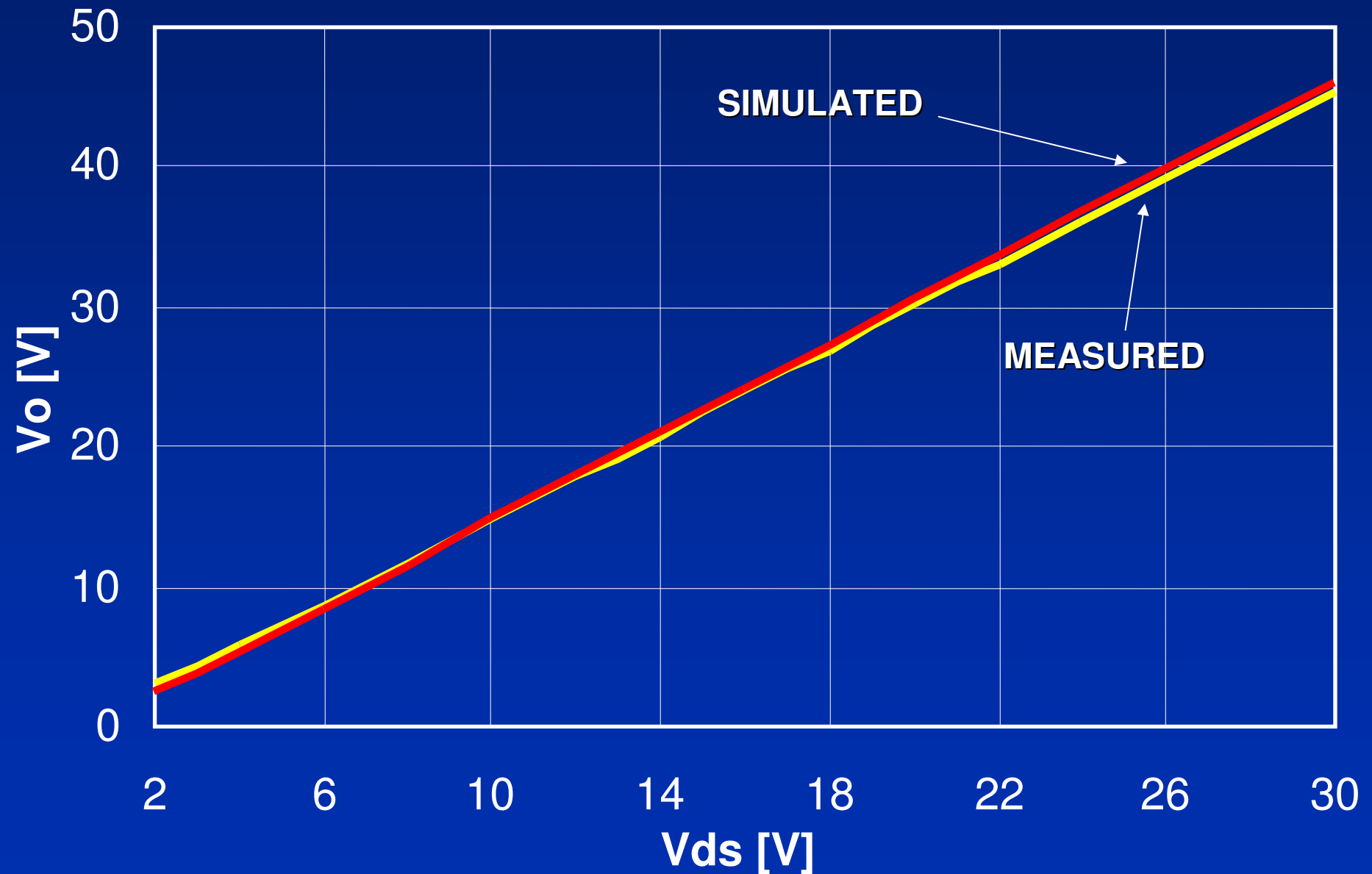
Drain efficiency vs. drain voltage



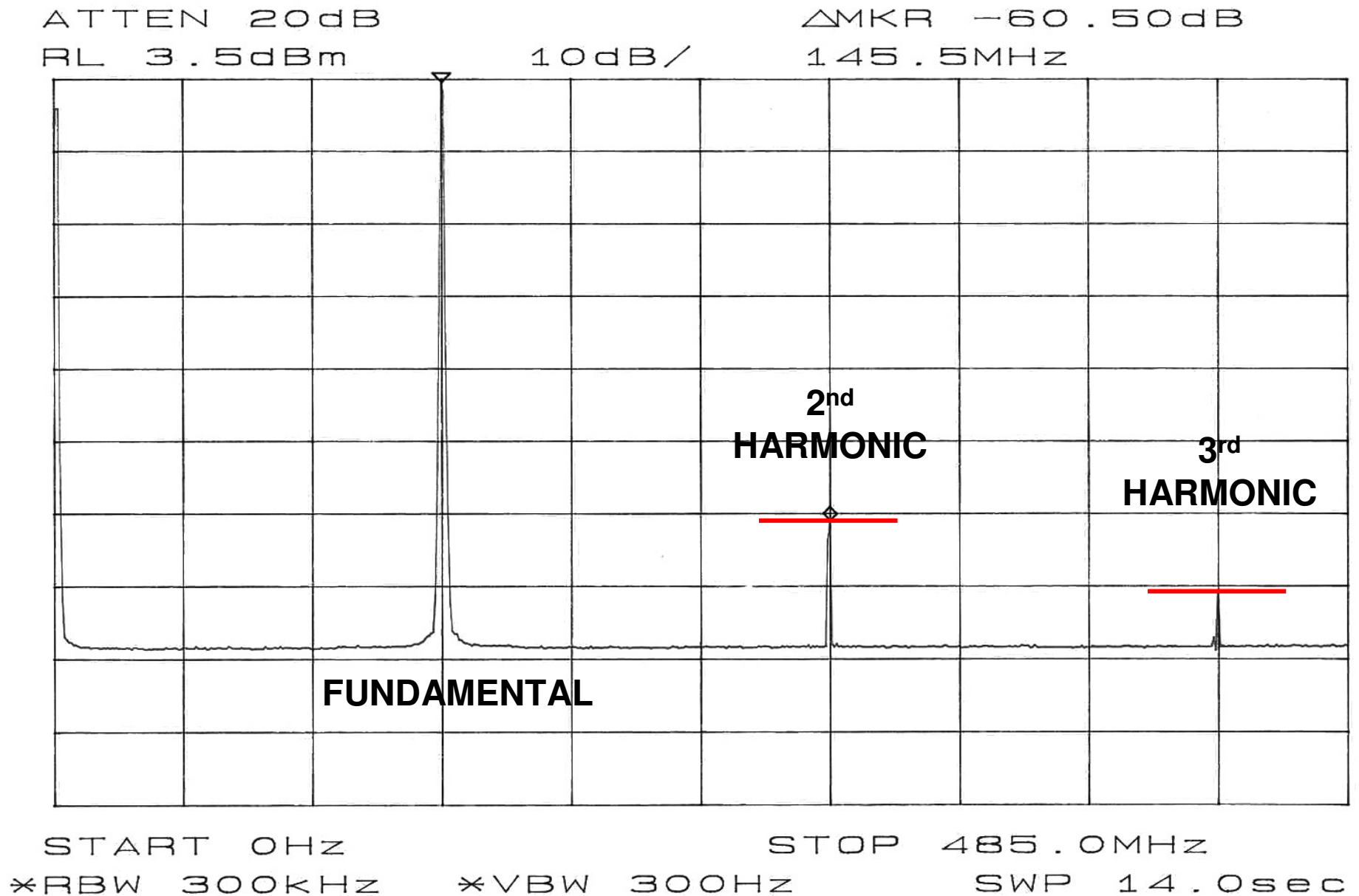
Power added efficiency vs. drain voltage



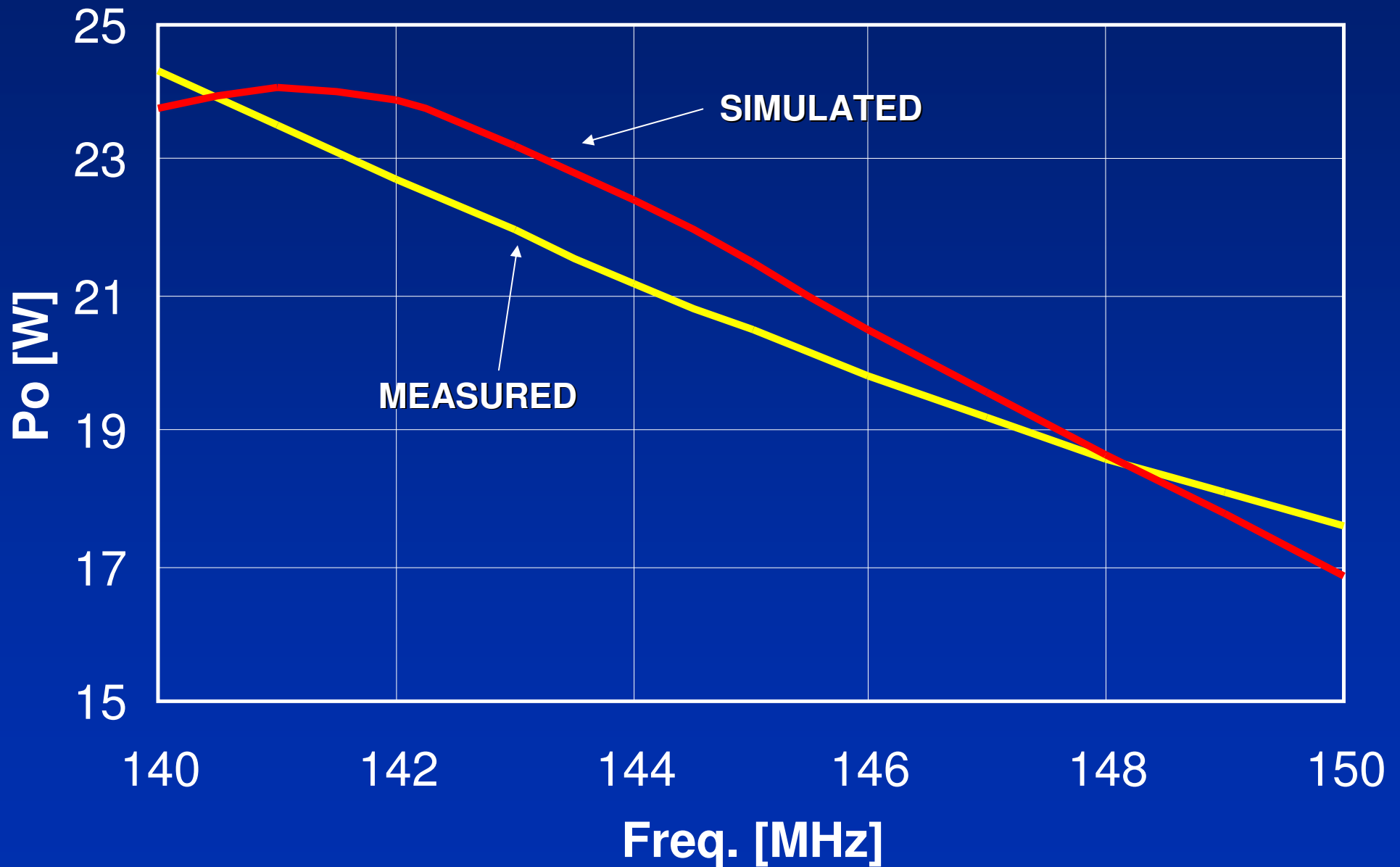
RF output voltage vs. drain voltage



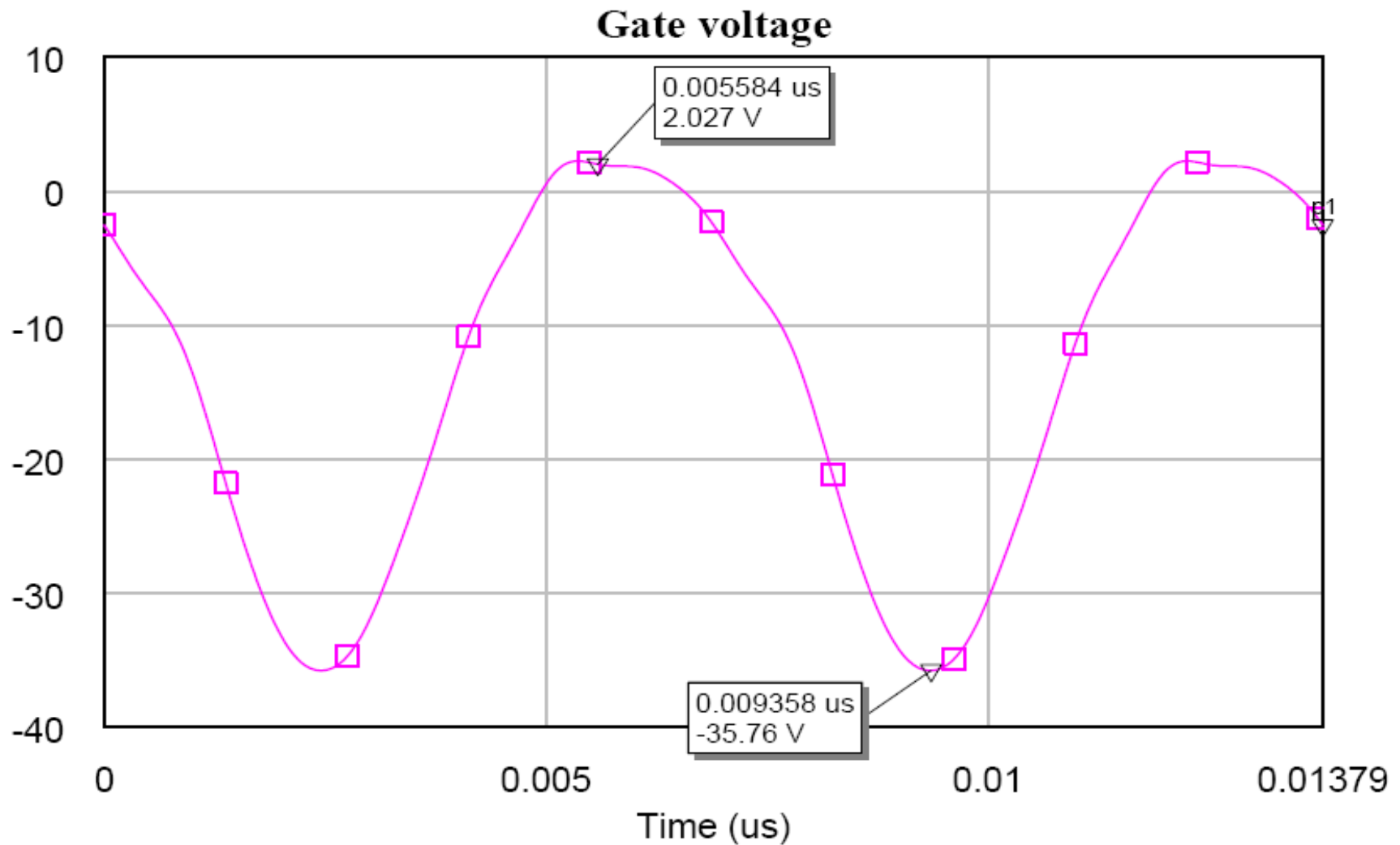
Output spectrum



Output power vs. frequency



Gate waveform



— Vtime(SUBCKT.S1@1,1)[1,31] (V)
2m AMPLIFIER

p1: Freq = 0.145 GHz
drainvolt = 30 V

Summary of results

Parameter	Simulated	Measured
Maximum Output Power	21.5 W	20.5 W
Nominal Input Power	27 dBm	27 dBm
Maximum Drain Efficiency	88 %	86.8 %
Maximum Power Added Efficiency	84.8 %	83.5 %
Maximum spurs and harmonics	-58 dBc	-58 dBc
Gain	16.3 dB	16.11 dB

Conclusion

- SiC devices can be successfully used in class-E VHF operation
- This amplifier can be used on AMSAT Eagle's 2 meter downlink phase array
- Very high efficiency can be achieved (~87%)
- Greater break-down voltage than GaAs allows for high power amplifier designs
- No oxide layer – advantage over LDMOS for space applications
- Very high operating temperature (120 °C case, 255 °C junction)

Thank you for your attention